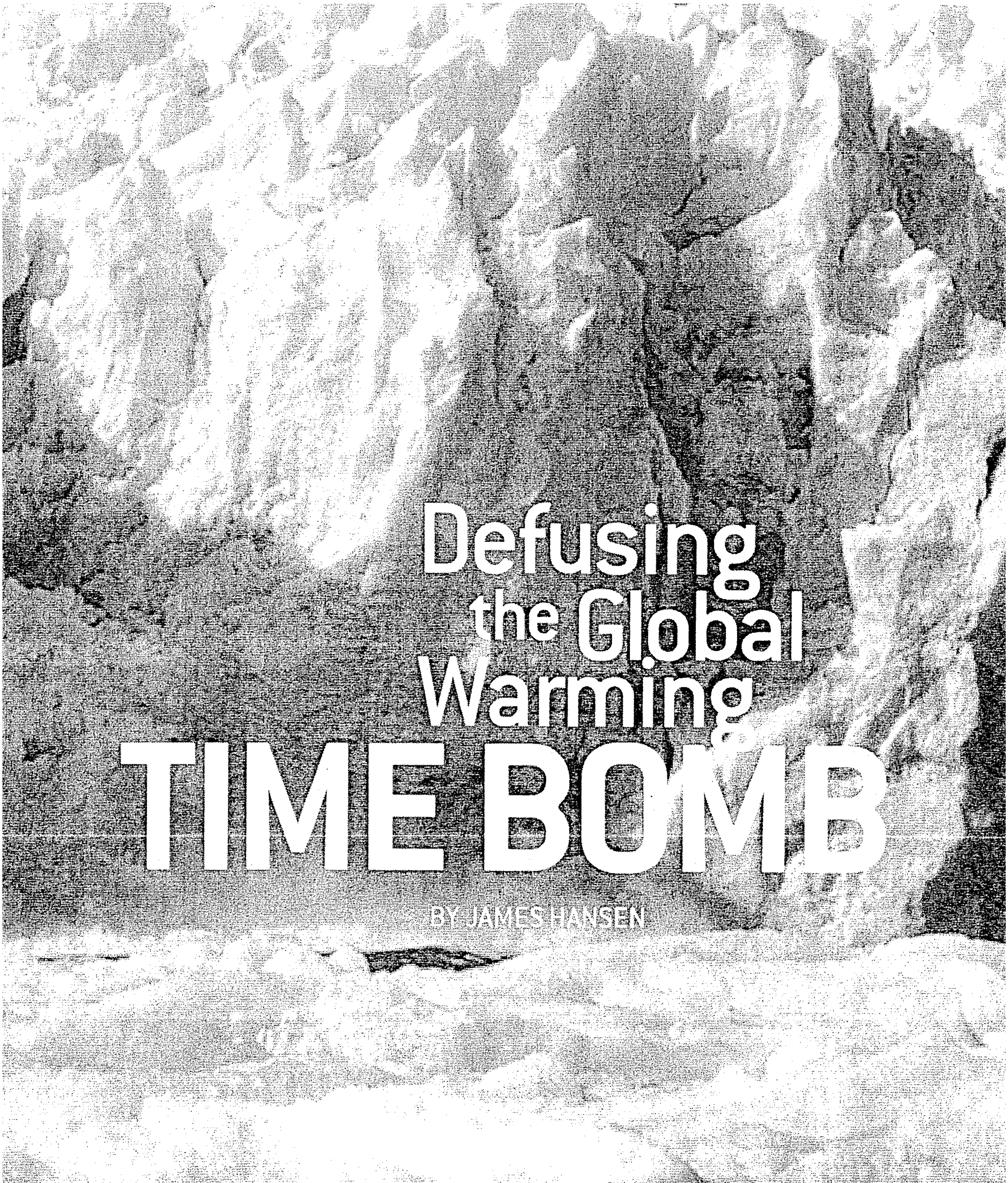
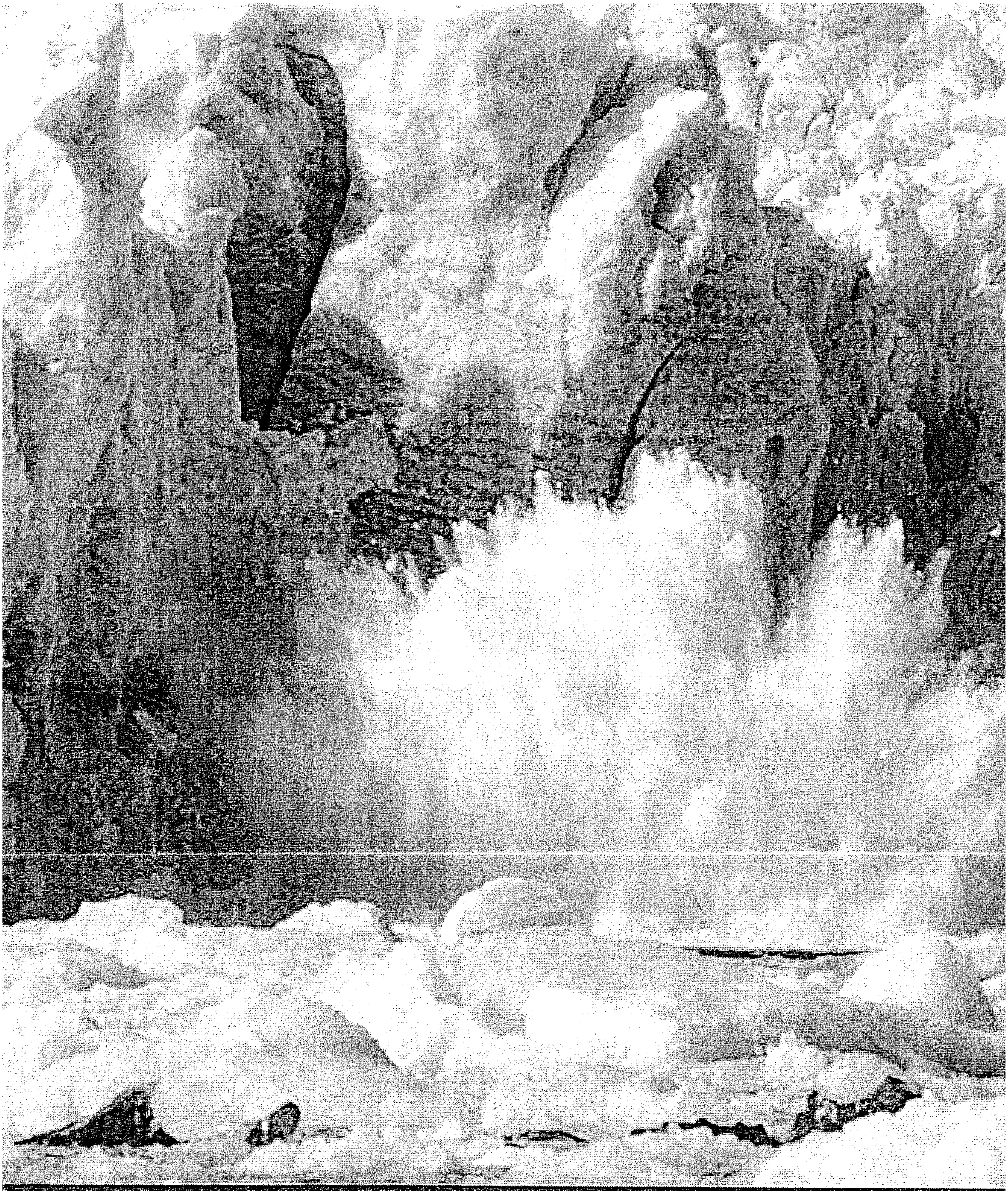


# Defusing the Global Warming TIME BOMB

BY JAMES HANSEN

**the consequences are potentially disastrous.**

would also yield a cleaner, healthier atmosphere, could slow, and eventually stop, the process



ICEBERG BREAKS OFF the San Rafael Glacier in Chile. Global disintegration of ice masses has the potential to raise sea level by several meters or more. The grim consequences of a rising sea level set a low threshold for how much the planet can warm without disrupting human society.

# Global warming is real, and

## Nevertheless, practical actions, which

paradox in the notion of human-made global warming became strikingly apparent to me one summer afternoon in 1976 on Jones Beach, Long Island. Arriving at midday, my wife, son and I found a spot near the water to avoid the scorching hot sand. As the sun sank in the late afternoon, a brisk wind from the ocean whipped up whitecaps. My son and I had goose bumps as we ran along the foamy shoreline and watched the churning waves.

That same summer Andy Lacis and I, along with other colleagues at the NASA Goddard Institute for Space Studies, had estimated the effects of greenhouse gases on climate. It was well known by then that human-made greenhouse gases, especially carbon dioxide and chlorofluorocarbons (CFCs), were accumulating in the atmosphere. These gases are a climate "forcing," a perturbation imposed on the energy budget of the planet. Like a blanket, they absorb infrared (heat) radiation that would otherwise escape from the earth's surface and atmosphere to space.

Our group had calculated that these human-made gases were heating the earth's surface at a rate of almost two watts per square meter. A miniature Christmas tree bulb dissipates about one watt, mostly in the form of heat. So it was as if humans had placed two of these tiny bulbs over every square meter of the earth's surface, burning night and day.

The paradox that this result presented was the contrast between the awesome forces of nature and the tiny lightbulbs. Surely their feeble heating could not command the wind and waves or smooth our goose bumps. Even their imperceptible heating of the ocean surface must be quickly dissipated to great depths, so it must take many years, perhaps centuries, for the ultimate surface warming to be achieved.

This seeming paradox has now been largely resolved through study of the history of the earth's climate, which reveals that small forces, maintained long enough, can cause large climate change. And, consistent with the historical evidence, the earth has begun to warm in recent decades at a rate predicted by climate models that take account of the atmospheric accumulation of human-made greenhouse gases. The warming is having noticeable impacts as glaciers are retreating worldwide, Arctic sea ice has thinned, and spring comes about one week earlier than when I grew up in the 1950s.

Yet many issues remain unresolved. How much will climate change in coming decades? What will be the practical consequences? What, if anything, should we do about it? The debate over these questions is highly charged because of the inherent economic stakes.

Objective analysis of global warming requires quantitative knowledge of three issues: the sensitivity of the climate system to forcings, the forcings that humans are introducing, and the time required for climate to respond. All these issues can be studied with global climate models, which are numerical simulations on computers. But our most accurate knowledge about climate sensitivity, at least so far, is based on empirical data from the earth's history.

## Overview/*Global Warming*

- At present, our most accurate knowledge about climate sensitivity is based on data from the earth's history, and this evidence reveals that small forces, maintained long enough, can cause large climate change.
- Human-made forces, especially greenhouse gases, soot and other small particles, now exceed natural forces, and the world has begun to warm at a rate predicted by climate models.
- The stability of the great ice sheets on Greenland and Antarctica and the need to preserve global coastlines set a low limit on the global warming that will constitute "dangerous anthropogenic interference" with climate.
- Halting global warming requires urgent, unprecedented international cooperation, but the needed actions are feasible and have additional benefits for human health, agriculture and the environment.

## The Lessons of History

OVER THE PAST few million years the earth's climate has swung repeatedly between ice ages and warm interglacial periods. A 400,000-year record of temperature is preserved in the Antarctic ice sheet, which, except for coastal fringes, escaped melting even in the warmest interglacial periods. This record [*see box on opposite page*] suggests that the present interglacial period (the Holocene), now about 12,000 years old, is already long of tooth.

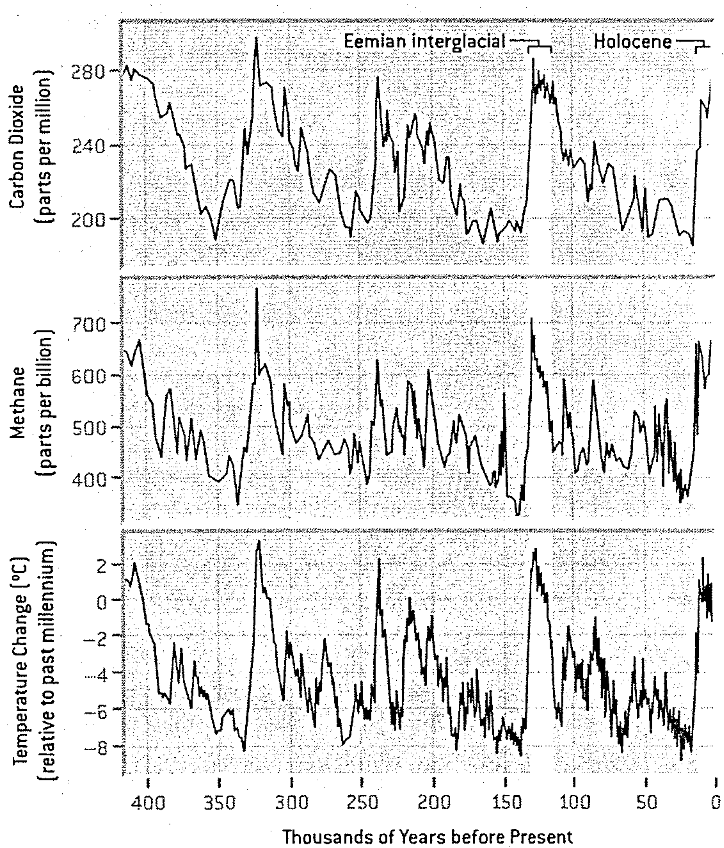
The natural millennial climate swings are associated with slow variations of the earth's orbit induced by the gravity of other planets, mainly Jupiter and Saturn (because they are so heavy) and Venus (because it comes so close). These perturbations hardly affect the annual mean solar energy striking the earth, but they alter the geographical and seasonal distribution of incoming solar energy, or insolation, as much as 20 percent. The insolation changes, over long periods, affect the building and melting of ice sheets.

Insolation and climate changes also affect uptake and release of carbon dioxide and methane by plants, soil and the ocean. Climatologists are still developing a quantitative understanding of the mechanisms by which the ocean and land release carbon dioxide and methane as the earth warms, but the paleoclimate data are already a gold mine of information. The most critical insight that the ice age climate swings provide is an empirical measure of climate sensitivity.

The composition of the ice age atmosphere is known precisely from air bubbles trapped as the Antarctic and Greenland ice sheets and numerous mountain glaciers built up from annual snowfall. Furthermore, the geographical distributions of the ice sheets, vegetation cover and coastlines during the ice age are well mapped. From these data we know that the change of

RIC ERGENBRIGHT *Corbis* (*preceding pages*)

## 400,000 YEARS OF CLIMATE CHANGE




ANTARCTIC ICE has preserved a 400,000-year record of temperature and of levels of carbon dioxide and methane in the atmosphere. Scientists study gases trapped in air bubbles in the ice—generally using ice cores (*photograph*) extracted from the ice sheet and transported to a laboratory. The historical record provides us with two critical measures: Comparison of the current interglacial period (the Holocene) with the most recent ice age (20,000 years ago) gives an accurate measure of climate sensitivity to forcings. The temperature in the previous interglacial period (the Eemian), when sea level was several meters higher than today, defines an estimate of the warming that today's civilization would consider to be dangerous anthropogenic interference with climate.

JEN CHRISTIANSEN; SOURCE: J. R. PETIT ET AL. IN *NATURE*, VOL. 399, PAGES 429–436; JUNE 3, 1999 (*graphs*); CSIRO/SIMON FRASER *Photo Researchers, Inc.* (*photograph*)

climate forcing between the ice age and today was about 6.5 watts per square meter. This forcing maintains a global temperature change of 5 degrees Celsius (9 degrees Fahrenheit), implying a climate sensitivity of 0.75 ± 0.25 degrees C per watt per square meter. Climate models yield a similar climate sensitivity. The empirical result is more precise and reliable, however, because it includes all the processes operating in the real world, even those we have not yet been smart enough to include in the models.

The paleodata provide another important insight. Changes of the earth's orbit instigate climate change, but they operate by altering atmosphere and surface properties and thus the planetary energy balance. These atmosphere and surface properties are now influenced more by humans than by our planet's orbital variations.

## Climate-Forcing Agents Today

THE LARGEST change of climate forcings in recent centuries is caused by human-made greenhouse gases. Greenhouse gases in the atmosphere absorb heat radiation rather than letting it escape into space. In effect, they make the proverbial blanket thicker, returning more heat toward the ground rather than letting it escape to space. The earth then is radiating less energy to space than it absorbs from the sun. This temporary planetary energy imbalance results in the earth's gradual warming.

Because of the large capacity of the oceans to absorb heat, it takes the earth about a century to approach a new balance—that is, for it to once again receive the same amount of energy from the sun that it radiates to space. And of course the balance is reset at a higher temperature. In the meantime, before it achieves this equilibrium, more forcings may be added.

The single most important human-made greenhouse gas is carbon dioxide, which comes mainly from burning fossil fuels (coal, oil and gas). Yet the combined effect of the other human-made gases is comparable. These other gases, especially tropospheric ozone and its precursors, including methane, are ingredients in smog that damage human health and agricultural productivity.

Aerosols (fine particles in the air) are the other main human-made climate forcing. Their effect is more complex. Some "white" aerosols, such as sulfates arising from sulfur in fossil fuels, are highly reflective and thus reduce solar heating of the earth; however, black carbon (soot), a product of incomplete combustion of fossil fuels, biofuels and outdoor biomass burning, absorbs sunlight and thus heats the atmosphere. This aerosol direct climate forcing is uncertain by at least 50 percent, in part because aerosol amounts are not well measured and in part because of their complexity.